

# Fermilab Theory Group

Christopher T. Hill

URA Annual Program Review  
Fermilab, April 22-23, 2005

## Scientists (12)

Bill Bardeen

Marcela Carena

Estia Eichten

Keith Ellis

Walter Giele

Christopher Hill

Andreas Kronfeld

Joe Lykken

Paul Mackenzie

Ulrich Nierste\*

Stephen Parke

Chris Quigg

## Associate Scientists (2)

Thomas Becher (9/04)

Bogdan Dobrescu

## Senior Guest Scientist(1)

Boris Kayser

## Research Associates (8)

Ayres Freitas

Ulrich Haisch

Jim Laiho

Olga Mena

Masataka Okamoto

Jose Santiago

Peter Skands

Giulia Zanderighi

## Users

C. Albright (NIU)

Alex Kagan(Cincinnati)






Y. Keung (UIC)

S.P. Martin (NIU)

Ulrich Baur (Buffalo)

\*Departs for Karlsruhe, 9/01/05


## Departures:

Ayres Freitas  Zurich ETH  
Giulia Zanderighi  CERN  
Uli Haisch  Zurich ETH  
Masataka Okamoto  KEK  
Ulrich Nierste  Karlsruhe (Professor)

## New Postdoc Hires arrived Fall 2004:

Jack Laiho (from Princeton),  
Peter Skands (from Lund),  
Jose Santiago (from Durham)

## New Postdoc Hires to arrive Fall 2005:

Jay Hubicz (from Cornell),  
Mu-Chun Chen (from BNL),  
Enrico Lunghi (from Zurich)  
(Frank Petriello  Madison, Asst. Professor)

## Associate Scientist Search:

Thomas Becher arrived 9/04

Freddie Cachazo (offered)

## History of the Post-Docs, Associate Scientists and Frontier Fellows is posted on the web:

<http://theory.fnal.gov/people/ellis/alumni.html>

<http://theory.fnal.gov/people/ellis/Assoc.html>

<http://theory.fnal.gov/people/ellis/frontier.html>

# The Fermilab Theory Group Visitor Programs

## Frontier Fellows

Senior distinguished visitors spending research time at Fermilab.

(Zerwas, Han, Boos, Love, Paschos, in academic year 2004/2005; Langacker in Fall 05)

## Latin American Scholars Program

Two excellent young physicists per year for 6 months come to study/work/collaborate in theory group:

2004: Alejandro Daleo (Argentina), Julian Candia (Argentina)

2005: Roberto Papaqui (Mexico), Alejandro Szynkman (Argentina)

## Summer visitors

In the past 30 visitors spending about 2-3 weeks each during the summer. Currently down to 22 person-weeks due to budget constraints.

## Short term visits

Miscellaneous scientific collaborators and workshop participants. (e.g., Isadori, Delgado, Minakata, Mahlon, Plehn, Haber, ... )

## Seminar Speakers

Theoretical seminar (48 speakers in 2004);

Joint Experimental-Theoretical Seminar (46 speakers in calendar 2004).

## Recent Frontier Fellows and Academic Visitors:

Vernon Barger (10-12/98)

Howard Haber (9-12/98)

Stuart Raby (2-6/99)

Wu-Ki Tung (2-6/00)

Stefan Pokorski (9-12/00)

Jo Anne Hewett (9-12/00)

Mariano Quiros (9-12/01)

Ken Lane (9-2/02)

Eric Braaten (10-12/02)

Aida El-Khadra (7-12/02)

Tao Han (10/04 –12/04)

Edward Boos (10/04 –12/04)

Paul Langacker (9/05 – 2/06)

Thomas Appelquist (10-12/98)

Pierre Ramond (6/99; 5/00)

Steve Ellis (3-6/00)

Moshe Moshe (3-9/00)

Mariano Quiros (9-12/00)

Alexei Yu. Smirnov (4/01)

Steve Gottlieb (9-6/02)

Ulrich Baur (2-4/02)

Scott Willenbrock (7-12/02)

Peter Zerwas (9-11/04)

Manny Paschos (10/04 –12/04)

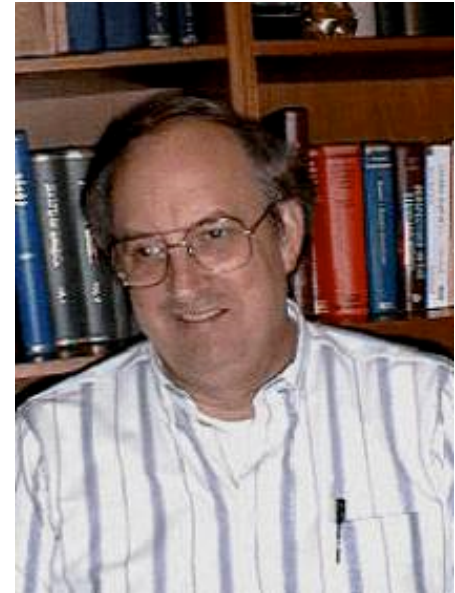
Sherwin Love (1/05 –04/05)

Frank Petriello (spring 2006)



# **Bill Bardeen Symposium - Fermilab -**

September 23-24, 2005  
9:00 am - 5:00 pm



## **Confirmed Invited Speakers include:**

Stephen Adler, Tom Appelquist, Andrzej Buras, Sally Dawson,  
Harald Fritzsch, Mary K. Gaillard, Roberto Peccei,  
Mike Turner, Henry Tye, Bruno Zumino, ...

**AGENDA (to appear)**

**Link to registration (there will be no registration fee)**

# The Major Questions of Particle Physics:

What is the source of Electroweak Symmetry Breaking?

Bardeen, Carena, Dobrescu, Eichten, Hill, Lykken, Quigg, Santiago

Is Supersymmetry associated with the phenomenon?

Carena, Dobrescu, Nierste, Freitas, Santiago

Are extra dimensions to be found near the Electroweak Scale?

Carena, Dobrescu, Hill, Lykken, Santiago

What is the origin and physics of Neutrino Mass?

Kayser, Mena, Lykken, Parke, Quigg

What are the indirect signatures in Flavor Physics?

Bardeen, Eichten, Hill, Nierste, Haisch, Quigg

How do we extract new physics that's buried under or within QCD?

**Lattice:** Bardeen, Eichten, Kronfeld, Mackenzie, Okamoto, Laiho,

**Perturbative:** Ellis, Giele, Zanderighi, Skands, Freitas, Haisch

How is particle physics connected to Cosmology and Astrophysics?

Carena, Hill, Lykken, Quigg, Mena

# Publications, Conference Proceedings, Reports

2004 calendar

• Senior Staff Scientific Publications:	32
• Senior Staff Conference Proceedings:	24
• Senior Staff Miscellaneous and Committee Reports:	7
• Research Associate Scientific Publications: *	26
• Research Associate Conference Proceedings:	8

(\* not counting newly arrived Research Associates)



## Staff Research Highlights 2004-2005 (partial list)

**Bill Bardeen** - completed study of the realization of chiral symmetries in lattice QCD with Wilson-Dirac Fermions. With Eichten and Thacker careful study of the chiral limit in the modified quenched approximation (MQA). Chiral supermultiplet theory: a string model.

**Thomas Becher** - focused on the theoretical description of B-meson decays, in particular decays to light hadrons, and a detailed analysis of the heavy-to-light meson transition form factors. Hard-scattering contributions to the form factors at large recoil were studied and large logarithms arising from multiple energy scales were resummed by matching QCD onto SCET via an intermediate effective theory. We prove a factorization theorem for the radiative decays  $B \rightarrow V + \gamma$  and present improved predictions for the branching ratios.

**Marcela Carena** – studied many different aspects of Higgs physics, supersymmetry, finite temperature phenomena, extra dimensions and gravity, electroweak baryogenesis,  $Z'$  physics.

**Bogdan Dobrescu** - studied the theoretical and experimental constraints on theories with a  $Z'$  gauge boson, concentrating on the discovery potential of the Tevatron. CDF is implementing results in their searches for s-channel resonances. Studied the possibility that massless gauge bosons other than the photon exist.

**Estia Eichten** - included electromagnetic effects in unquenched Lattice QCD simulations. With Lane and Quigg, studied effects of coupling to decay channels in the charmonium system, important to understand the nature of the  $X(3872)$  state discovered at BELLE and confirmed by CDF and D0.

**Keith Ellis** - focus has been the parton-level Monte Carlo MCFM. Version 4 released October 15, 2004, contains all the single top processes relevant to Tevatron at NLO, including the semi-leptonic decay of the top quark. Can be used to estimate global event properties which are useful to distinguish between single top backgrounds and signal, and now being used by the experimenters.



## Research Highlights 2004-2005 (cont'd)

Walter Giele - development of dipole shower Monte Carlo to overcome shortcomings in the current shower Monte Carlo's (such as HERWIG and PYTHIA). Development of a semi-numerical approach to evaluate one-loop matrix elements (Zanderighi and Ellis).

Christopher Hill – Studied topological properties of Yang-Mills field theories in higher dimensions. With Zachos, showed that the D=5 Yang-Mills Chern-Simons terms under compactification to D=4, become the Wess-Zumino-Witten terms of a chiral lagrangian. In October, my book “Symmetry and the Beautiful Universe” (with Leon Lederman) appeared.

Andreas Kronfeld - lattice QCD calculations (finally!) agree with experimental measurements for a wide variety of mass and matrix elements. Key ingredient was an improved action for staggered quarks. Our (still preliminary) decay constant for the D meson agrees with the result of CLEO-c.

Joe Lykken - studying the phenomenology of realistic intersecting D-brane models. We are studying a class of models which are both well-motivated and pose interesting experimental challenges for the LHC.

Paul Mackenzie - First results of our program of B and D meson physics were published this year, based on work with the MILC collaboration and Cornell collaboration. These are prime ingredients of the determination of CKM matrix elements from experiment.

Ulrich Nierste - computed (with Junger) the constraint from  $\tau \rightarrow \mu \gamma$  on the parameters of the Cheng-Masiero-Murayama-model and have analyzed the effect on  $B_s$ - $B_s$ -bar mixing. Calculation of the branching fraction of the decay  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  to NNLO (with Haisch and Gorbahn) is nearly complete.

## Research Highlights 2004-2005 (cont'd)

Stephen Parke - showed (with Mena) how to untangle the neutrino mass hierarchy and CP violation in Long Baseline Experiments. With Nunokawa and Zukanovich-Funchal calculated the fraction of B8 solar neutrinos that are  $\nu_2$  mass eigenstates (90%); developed alternative way to determine the mass hierarchy using disappearance experiments only.

Chris Quigg – with Barenboim, Mena, examined absorption lines caused by the annihilation of ultrahigh-energy neutrinos on the relic neutrino background. The sensitivity of the absorption spectra to the thermal history of the universe led us to suggest the possibility of an “undulant universe” whose expansion is characterized by alternating eras of acceleration and deceleration.

## Outreach and Policy

- M. Carena** - Fermilab Long Range Planning Committee;  
Member of the Subatomic Grant Selection Committee in Canada,  
October 2002 - October 2005  
Executive Committee of the Division of Particles and Fields of the American  
Physical Society. January 2003 - December 2005  
Chair of Organizing Committee of the TeV4LHC Workshop on Tevatron and LHC  
Physics, Meetings at Fermilab, BNL and CERN. May 2004 - October 2005
- B. Dobrescu** - Convenor at the TeV4LHC Workshop (Fermilab, BNL, CERN, 2004-2005).  
Convenor at the SUSY04 Conference (Tsukuba, Japan, June 2004).  
Organizer of the Workshop on “From Zero to Z-Zero: Precision Electroweak  
Physics” (Fermilab, May 2004). Organizer of the Joint Experimental-Theoretical  
Seminar.
- E. Eichten** - APS Investment Sub-committee
- C. Hill** - Fermilab Long Range Planning Committee;  
Scientist III Promotion Committee (chair);  
Head of Fermilab Theoretical Physics Department.

## Outreach and Policy

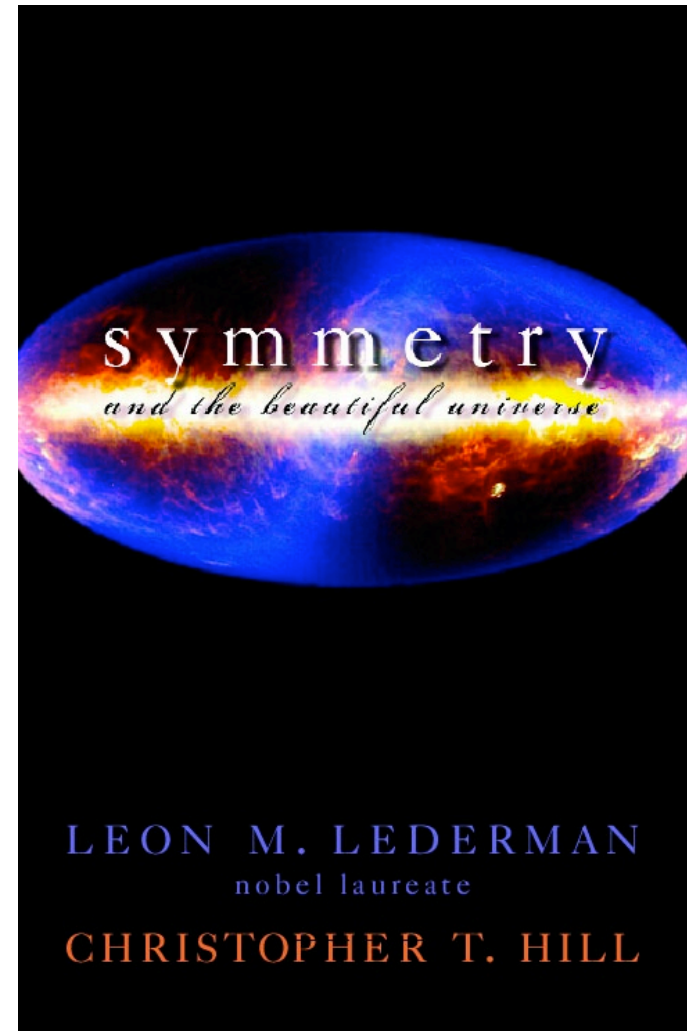
- B. Kayser** - Editor of Annual Review of Nuclear and Particle Science, Fermilab Program Advisory Committee  
Particle Physics Project Prioritization Panel (P5).
- A. Kronfeld** - member of the Organizing Committee for the World-Wide Study of Physics and Detectors at Future Linear  $e^+e^-$  Colliders.
- J. Lykken** - PAC, EPAC, TASI, MUTAC, Aspen, Fermilab Director Search Committee
- P. Mackenzie** - DOE SciDAC, National Committee, Advisor to KEK on Large Scale Simulation; FCSA
- U. Nierste** - Chicagoland Flavor Workshop; convener of the SUSY 2004 conference in Tsukuba, local organizing committee of the "Kaon'05"
- S. Parke** - contributed to the NOvA proposal as well as the Reactor White paper and the APS Neutrino Report
- C. Quigg** - Past chair of DPF, HEPAP, Program committee APS ; Albuquerque 2002 (chair), IMSA Board

“... In *Symmetry and the Beautiful Universe*, Leon Lederman and Chris Hill have captured the essence of this simple yet profound concept and conveyed its wonders with art and precision. In accessible and entertaining language, the authors provide readers with a crystal-clear window to physics’ most refined theories, allowing us all to appreciate the awe-inspiring beauty of the universe.”

—Brian Greene, Author of *The Elegant Universe* and *The Fabric of the Cosmos*; Professor of Physics, Columbia University

“An enigma of twentieth-century physics is the question of symmetry as a guiding principle of nature. Did nature start with the idea of symmetry, or is it an accidental consequence? Is symmetry, with its aesthetic appeal, a fundamental principle? In this penetrating and lucid book the authors, both top physicists, take on symmetry as a basic principle. They succeed in a marvelous way, and consequently this book is a must for the serious student of nature.”

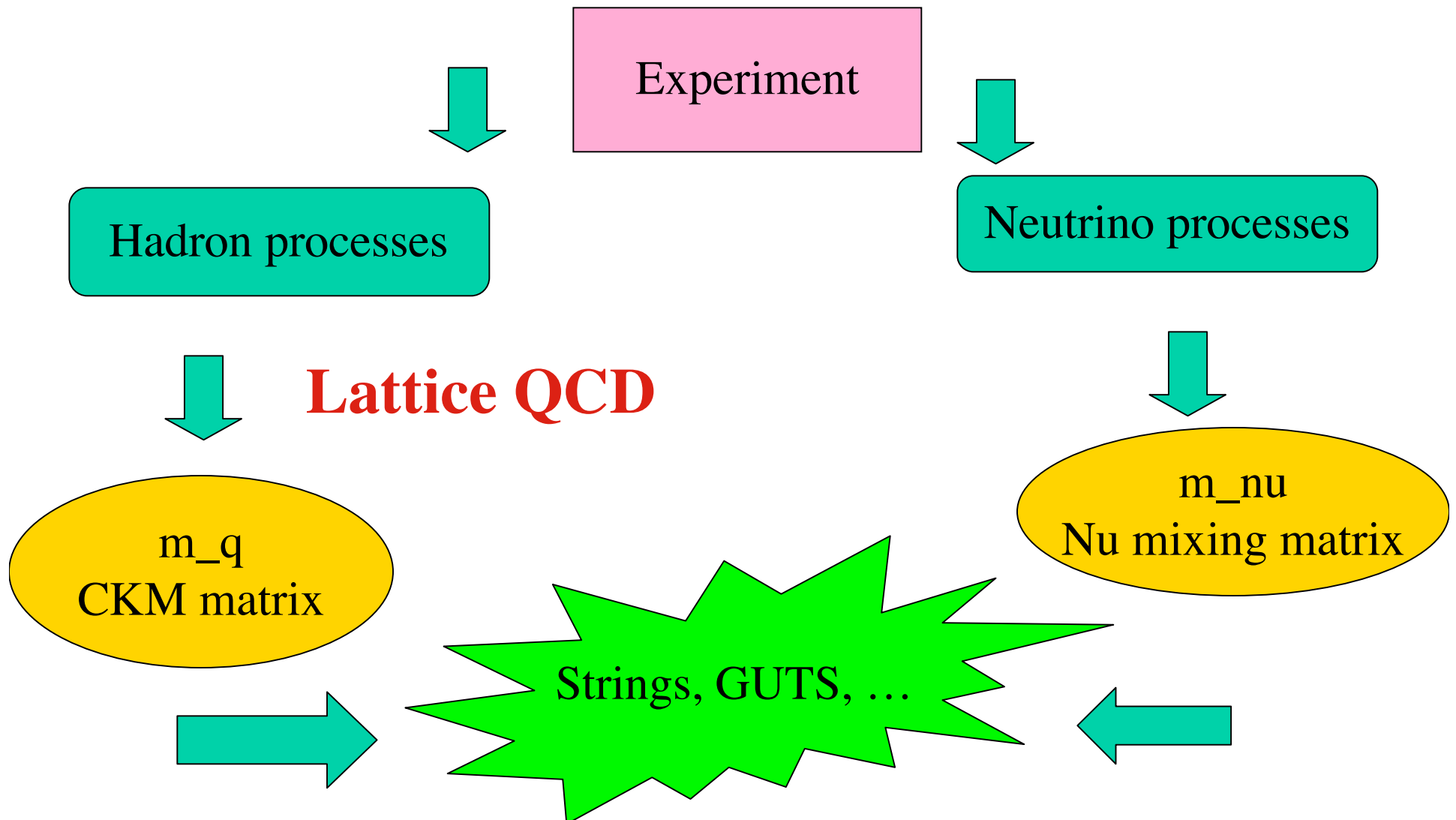
—Martinus Veltman, *Nobel Laureate*; Author of *Facts and Mysteries in Elementary Particle Physics*



# Lattice gauge theory.

Paul Mackenzie

Required to fully capitalize on DoE's investment in experiment.

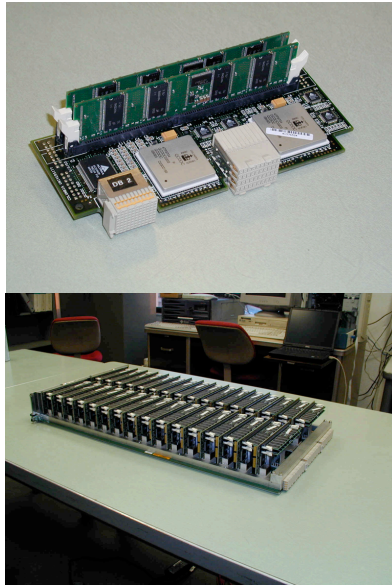


# The Department of Energy is establishing a US infrastructure for lattice QCD.

Currently > \$4M/year.

\$1/MF.

Software and two kinds of hardware.



The QCDOC, purpose-built for compute-intensive calculations (BNL).



Clusters, for I/O intensive, software-intensive analysis (Fermilab/Jlab).



## Fermilab lattice computing:

256 nodes installed 2004 ( GF).

512 nodes under construction 2005 (0.7 TF).

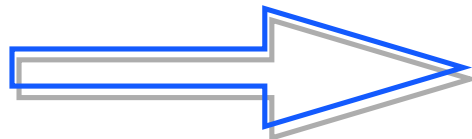
~1000 nodes planned 2006 (~2 TF).

## Fermilab/MILC 2005/2006 project:



Generate new gauge configurations on a QCDOC at BNL.

2 TF-years



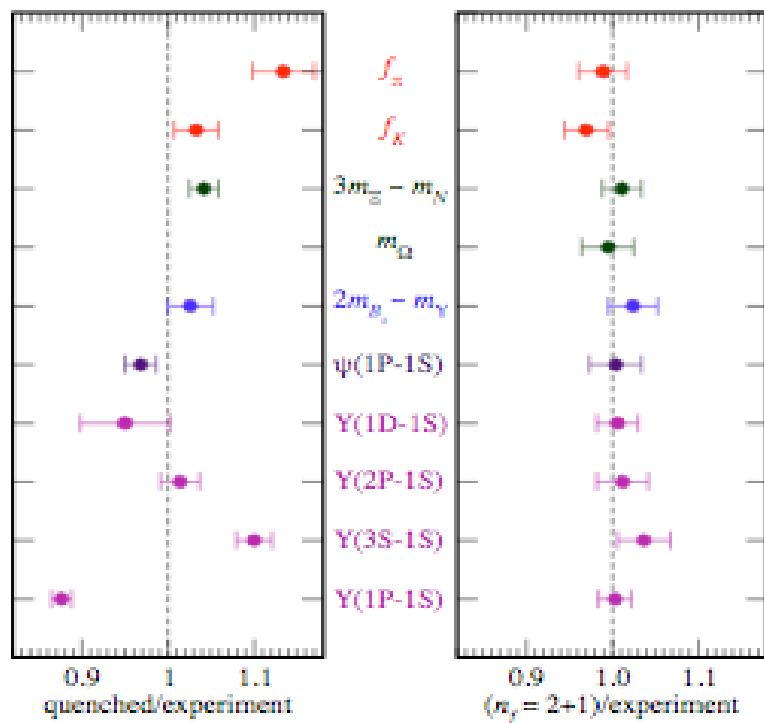
Few TB.



Transfer to Fermilab for analysis on clusters.

0.7 TF-years.

# Progress in lattice QCD phenomenology



Davies *et al*, hep-lat/0304004 + Toussaint, Davies, LAT04

Fermilab, HPQCD, MILC

For sufficiently simple quantities, the 10%-ish errors visible in the “quenched approximation” have been removed with unquenched calculations using **improved staggered fermions**.

Processes with single, stable mesons are  
“golden quantities” for lattice QCD.

Best controlled errors, well measured experimentally.

$$\left( \begin{array}{ccc} \mathbf{V}_{ud} & \mathbf{V}_{us} & \mathbf{V}_{ub} \\ \pi \rightarrow l\nu & K \rightarrow \pi l\nu & B \rightarrow \pi l\nu \\ \mathbf{V}_{cd} & \mathbf{V}_{cs} & \mathbf{V}_{cb} \\ D \rightarrow \pi l\nu & D \rightarrow K l\nu & B \rightarrow D l\nu \\ D \rightarrow l\nu & D_s \rightarrow l\nu & \\ \mathbf{V}_{td} & \mathbf{V}_{ts} & \mathbf{V}_{tb} \\ \langle B_d | \bar{B}_d \rangle & \langle B_s | \bar{B}_s \rangle & \end{array} \right)$$

Most of the elements of the CKM matrix can be determined from such quantities.

Fermilab, with the MILC collaboration, is performing a systematic study of these quantities using improved staggered light quarks Fermilab clover heavy quarks.

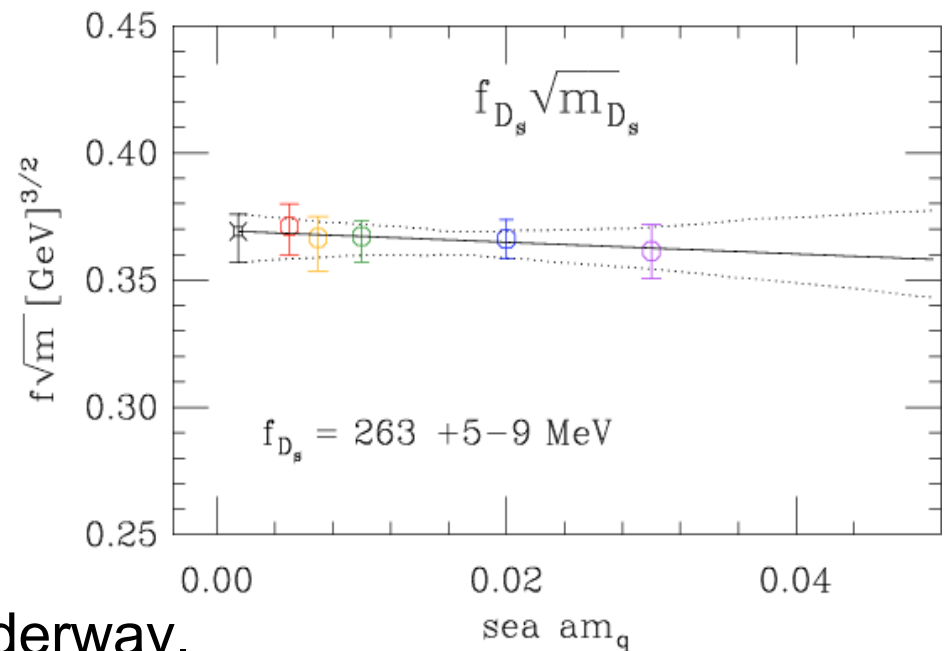
## D decay constants

From CLEO-c: new tests of lattice methods from CKM  
independent amplitude ratios:

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$$f_D/D \rightarrow \pi l \nu \text{ and } f_{D_s}/D \rightarrow K l \nu$$

$$\begin{aligned}\frac{f_{D_s} \sqrt{m_{D_s}}}{f_D \sqrt{m_D}} &= 1.20 \pm .06 \pm .06 \\ f_{D_s} &= 263^{+5}_{-9} \pm 24 \text{ MeV} \\ f_D &= 224^{+10}_{-14} \pm 22 \text{ MeV}\end{aligned}$$



B decay constants also underway.

Results for first fully unquenched  
 $B$  and  $D$  **semileptonic decays** (Masataka Okamoto).

$D \rightarrow K l \nu$  ,  $D \rightarrow \pi l \nu$  (nearly final results)

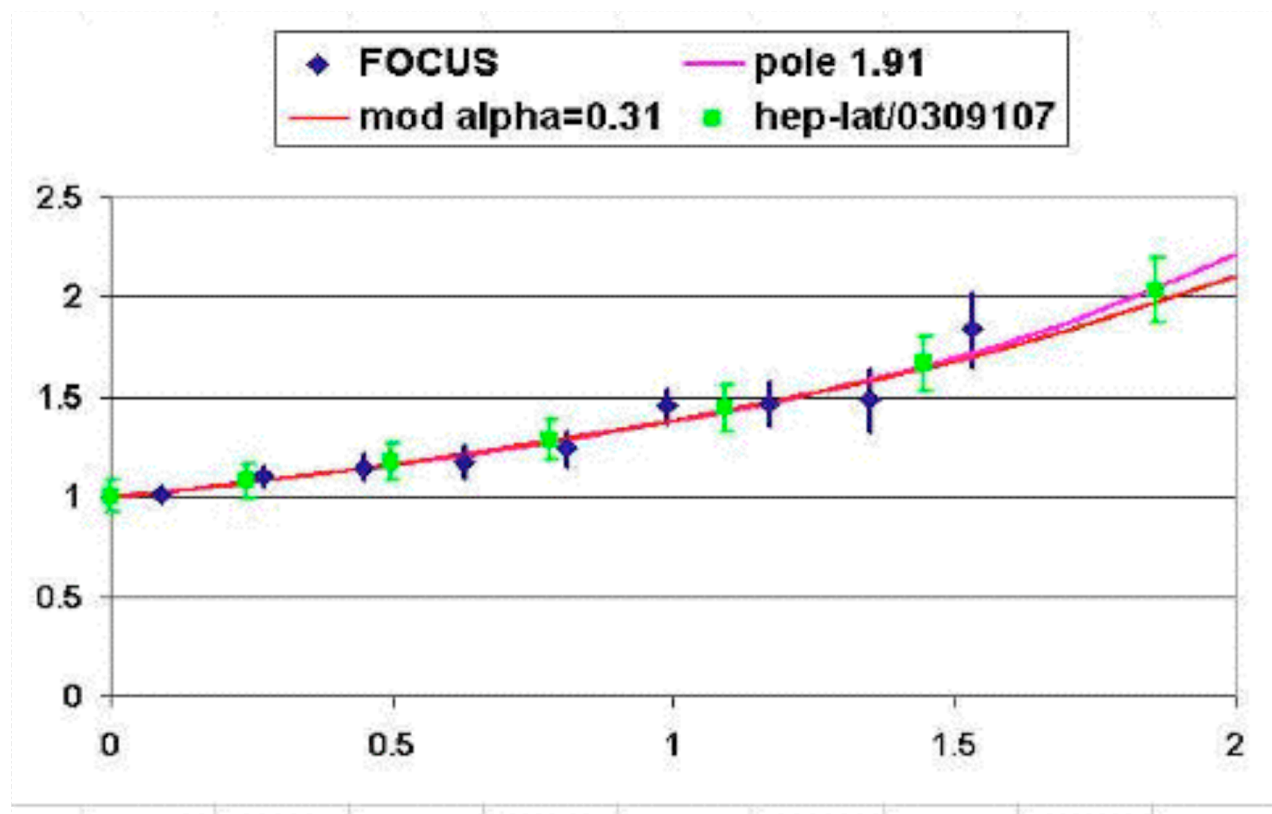
- $f_+^{D \rightarrow \pi}(0) = 0.64(3)(5)$
- $f_+^{D \rightarrow K}(0) = 0.73(3)(6)$

$B \rightarrow \pi l \nu$  ,  $B \rightarrow D l \nu$  (preliminary)

- $f_+^{B \rightarrow \pi}(0) = 0.24(3)(2)$
- $\mathcal{F}_{B \rightarrow D}(1) = 1.07(2)(2)$

## Comparison to FOCUS experiment for $D \rightarrow K$ decay

$f_+(q^2)/f_+(0)$  vs  $q^2$ :



(provided by FOCUS col

Results:

CKM matrix from unquenched lattice semileptonic decays.

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ N/A & N/A & 3.6(5)(4)(3) \times 10^{-3} \\ V_{cd} & V_{cs} & V_{cb} \\ 0.24(1)(2)(2) & 0.97(4)(8)(2) & 3.8(1)(1)(6) \times 10^{-2} \\ V_{td} & V_{ts} & V_{tb} \\ N/A & N/A & N/A \end{pmatrix}$$

Check unitarity of second row:

$$(|V_{cd}|^2 + |V_{cs}|^2 + |V_{cb}|^2)^{1/2} = 1.00(4)(8)(2)$$